International Journal of Computer Networking,
Wireless and Mobile Communications (IJCNWMC)
ISSN(P): 2250-1568; ISSN(E): 2278-9448
Vol. 5, Issue 6, Dec 2015, 9-18
© TJPRC Pvt. Ltd.

DESIGN OF GROUND STATION SMART ANTENNA SYSTEM FOR MULTIMEDIA COMMUNICATIONS IN SMALL DRONE APPLICATIONS

SETTAPONG MALISUWAN

National Broadcasting and Telecommunications Commission, Thailand, Bangkok

ABSTRACT

Since broadband and mobility communications is an unavoidable requirement according to the drone operation requirements. In this paper, a circularly polarized microstrip antenna array, as a part of smart antenna system, operating at 2.45GHz, is analyzed and designed. The return loss of the proposed microstrip patch antenna is simulated. The proposed 2×2 microstrip antenna array is designed and analyzed for ground station to be utilized in the small drone communication system. The FDSC model is adopted in this research to reduce the error on the frequency-dependent characteristics by including into the antenna design procedure. The proposed smart antenna system at ground station in this research is mainly applied for small drone applications with broadband and mobility requirements. The procedure in this research is compatible with Computer Aided Design (CAD) with fast and user-friendly implementations.

***KEYWORDS:** Micro Strip, Smart Antenna, Ground Station, Multimedia, Drone*

Received: Oct 19, 2015; **Accepted:** Oct 28, 2015; **Published:** Nov 04, 2015; **Paper Id.:** IJCNWMCDEC20152

Original Article

INTRODUCTION

Drone use has become popular in civil applications. While there are many of types of drones, they basically fall into two categories: those that are used for reconnaissance and surveillance purposes and those that are armed with missiles and bombs [1]. Today, drones are no longer considering high-tech or novel invention; it is an essential part of modern military operations. Yet, drones is lagging behind on civil usage due to non-technical issues such as regulation, security concerns, safety and liability, privacy and civil rights, etc [2]. Even so, a variety of models have been introduced and commercially sold in past few years and has grown in considerable popularity even with end users. Drones fly in an autonomous manner, and carry cameras for video recording and photography. There are a broad range of applications that will be dependent on drones, including aerial monitoring of industrial plants, factories, agricultural fields and it can even act as a first time responder for disasters in order to quickly assess the situation in preparation disaster response. Drones can be classified by size and weight, flight range, altitude and its engine type. The two main types are fixed-wing vehicles and multicopters. The flight scenario of the drone is shown in Figure 1.

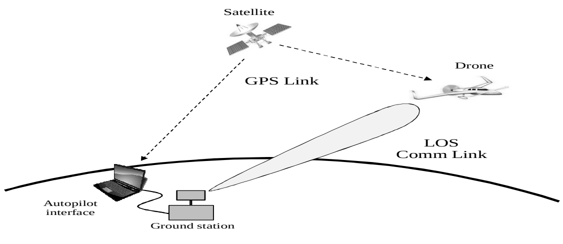


Figure 1: Flight Scenario

Long distance traveling drones operate on bandwidth range of 3 – 30MHz. Such long distance communications are possible through ionosphere reflections and atmospheric low-attenuation windows. As they are small in size, the size of HF antennas are particularly large compared to the size of the drone. This type of antenna is also narrowband and its flaw is low radiation resistance and inherent conductor losses. Therefore, broadband antennas that operate on HF to lower-UHF bands are not pragmatic for small drones. As a result, separate antenna systems are designed and implemented to accommodate different frequency bands to decrease the size of the antenna. Additionally, when designing the antenna to be placed on drone's platform, the materials and electronics used on the drone have to be taken into consideration in order to evaluate its impact on the antenna's performance.

Nowadays, the microstrip antennas continuously develop to become one of the most attractive antenna options in a wide range of modern microwave systems. This fast growth in microstrip antenna applications and uses derived a continuous research effort for developing and improving its characteristics [3]. In general, a microstrip antenna can attain a narrow frequency bandwidth at the expense of a low gain. As compared with conventional microwave antennas, a microstrip antenna has additional advantages such as a compact size, light weight, conformability to surfaces of substrates, low cost, and easier integration with other circuits and versatility [4]. From a designer point of view, a microstrip antenna presents a wide range of options. The designer can vary the choice of the substrate type, the antenna structure, type of perturbation and the feeding technique to achieve the antenna design objective [5].

Requirements for broadband and mobility drone communications are necessary in order to move large amounts of information in real-time. Therefore, the antenna system of the drone needs to be carefully designed to meet the requirement.

The objective of this paper is to design, a smart antenna system, a microstrip antenna array at the ground station that receives multimedia signal from the drone. The operating frequency of 2.4GHz ISM band is used to transmit the multimedia signal with required minimum bandwidth of 20MHz.

There is extensive literature that presented the design of rectangular microstrip antennas [6],[7]. However, previous studies have not included the effect of very high operating frequency in the procedure which increases chances calculation error in the model.

Therefore, the frequency-dependent Smith-Chart model (FDSC) is adopted in this research to reduce the error on the frequency-dependent characteristics [4]. Specifically, the frequency-dependent characteristic impedance included in the algorithm is addressed in great detail to eliminate possible errors in the high frequency. The results in [8],[9]suggests that FDSC gives more accurate results than the models adopted in past literature [10]. This research uses MATLAB programming to design and simulate the proposed smart antenna system.

This paper is structured as follows. Section II illustrates the frequency-dependent smith chart concept to include the effects of GHz frequency range into the antenna design model to reduce the error of calculations. The smart antenna system design procedure is introduced in detail in Section III and then conclusion.

Frequency-Dependent Smith-Chart Model

The FDSC model is proposed in the literature [9]. Microstrip-based Cole-Cole diagram is adopted to create the frequency-dependent (lossy) Smith-chart in order to study microstrip line characteristics [11].

The microstrip patch is usually made of gold or copper (conducting material) and the shape varies. The radiating patch and the feed lines are usually photo etched on the dielectric substrate as illustrated in Figure 2.

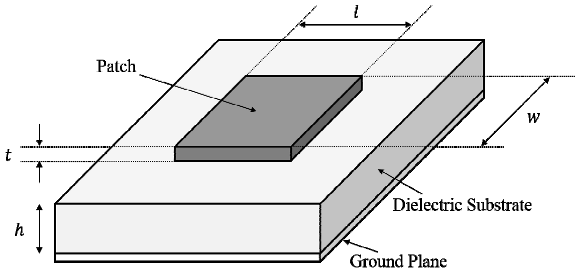


Figure 2: Structure of a Microstrip Patch Antenna

The capacitance parameter in microstrip-line system is studied before generating the frequency-dependent Smith-chart relations. The capacitance per unit length of the classical parallel-plate capacitor can be expressed as [4].

$$C = \varepsilon \frac{w}{h} \tag{1}$$

A simple frequency-dependent capacitance of the parallel-plate capacitor can be expressed in any frequency-dependent attributes of ε which is

$$C(\omega) = \varepsilon_0 \varepsilon^*(\omega) \frac{w}{h} \tag{2}$$

where $\varepsilon^*(\omega)$ is a complex permittivity is expressed as $\varepsilon'(\omega) - j\varepsilon''(\omega)$.

Therefore,

$$C(\omega) = \varepsilon_0 \varepsilon'(\omega) \frac{w}{h} - j\varepsilon_0 \varepsilon''(\omega) \frac{w}{h} \tag{3}$$

Referring to the equivalent Cole-Cole diagram deduced for a parallel-plate microstrip line in [10] is substitute into Eqn. (3). Hence,

$$C(\omega) = C\left(\frac{1}{1+Q(\omega)}\left[Q(\omega) + \frac{\varepsilon_{eff}(0)}{\varepsilon_r}\right]\right) - j\frac{C}{\varepsilon_r}\left[\varepsilon_u''(\omega) + \varepsilon_c''(\omega) + \varepsilon_d''(\omega)\right] \tag{4}$$

Where$C = \varepsilon_0 \varepsilon_r (w/h)$.

For simplicity, the coefficients of Eqn. (4) are defined as follows:

$$A(\omega) = \frac{1}{1+Q(\omega)}\left[Q(\omega) + \frac{\varepsilon_{eff}(0)}{\varepsilon_r}\right] \tag{5}$$

$$B(\omega) = \frac{1}{\varepsilon_r}\left[\varepsilon_u''(\omega) + \varepsilon_c''(\omega) + \varepsilon_d''(\omega)\right] \tag{6}$$

In general, the characteristic impedance of a transmission line is given by

$$Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}} \tag{7}$$

where R, L, G and C are per unit length quantities defined as follows:, R = resistance per unit length in Ω/m, L = inductance per unit length in H/m, G = conductance per unit length in S/m, C = capacitance per unit length in F/m. [8]

If G and C are neglected, the characteristic impedance can be written as:

$$Z_0 = \sqrt{\frac{L}{C}} \tag{8}$$

To achieve frequency-dependent characteristic impedance $(Z_0'(\omega))$, the frequency-dependent capacitance $(C(\omega))$of Eqn. (4) is replaced into the capacitance (C) in Eqn. (8).Therefore, frequency-dependent characteristic impedance is

$$Z_0'(\omega) = \sqrt{\frac{L}{C[A(\omega)-jB(\omega)]}} = \frac{Z_0}{\sqrt{A(\omega)-jB(\omega)}} \tag{9}$$

Now, the frequency-dependent (lossy) Smith-chart can be derived through input of $Z_0'(\omega)$ in Eqn. (9) into the normalized terminal impedance expression as done in traditional Smith-chart model [12].Therefore the normalized terminal impedance Z_L' is

$$Z_L' = \frac{Z_L}{Z_0'(\omega)} = br + jbx \text{ (Dimensionless)} \tag{10}$$

As r and x are the normalized resistance and normalized reactance and $b = \sqrt{A(\omega) - jb(\omega)}$.

The voltage reflection coefficient of present Smith chart is

$$\Gamma' = \Gamma_r' + j\Gamma_i' = \frac{Z_L'-1}{Z_L'+1} \tag{11}$$

or

$$Z_L' = \frac{Z_L}{Z_0'(\omega)} = br + jbx = \frac{(1+\Gamma_r')+j\Gamma_i'}{(1-\Gamma_r')-j\Gamma_i'} \tag{12}$$

Now, the set of equations representing the modified Smith-chart is expressed as:

$$\left(\Gamma_r' - \frac{br}{1+br}\right)^2 + \Gamma_i'^2 = \frac{1}{(1+br)^2} \tag{13}$$

and

$$(\Gamma_r' - 1)^2 + \left(\Gamma_i' - \frac{1}{bx}\right)^2 = \left(\frac{1}{bx}\right)^2 \tag{14}$$

It can be seen in [9] that when the lossy characteristics (substrate loss, conductor loss, and frequency-dependent characteristic impedance of the microstrip line) are included in the calculation. A known fact in lossy transmission line theory is that when attenuation as a function of line-length is plotted on the Smith chart, it takes the form of a spiral [9]

Smart Antenna System Design

As drone become smaller, antenna researchers have focused much of their effort on shrinking antennas designed for systems on those aircraft. Researchers have also endeavored to integrate antennas on small drone without impacting their aerodynamics.

One approach to the problem has been to use microstrip antennas, which are light-weight, planar, compact, and inexpensive. An antenna on a single layer microstrip is lighter and significantly cheaper. Therefore, communication applications on small drone, a single layer antenna is preferred.

Element and Array Designs

The polarization of an antenna is vital to its functionality. Any difference in the polarization characteristics between the transmit and receive antennas of a system results in polarization loss of power over the link. In order to avoid air-to-ground energy loss as a result of two misaligned linearly polarized antennas, it has been decided that both the transmitting and receiving antenna should be circularly polarized.

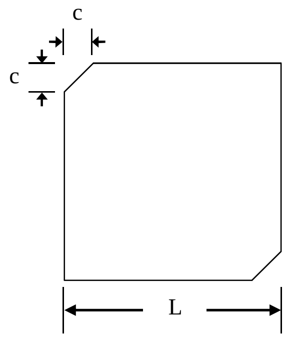


Figure 3: A Circularly Polarized Truncated Corner Microstrip Patch Antenna [13]

One common way of achieving circular polarization from a single feed patch is to feed the patch on one of the sides and truncate the corners of a square patch [14], as shown in Figure 3. If the corners were not truncated, one resonance mode will occur from the side that is feed to the opposite side. This would create linear polarization. When the corners are truncated, the resonance will not occur from one side to the other side, but along the diagonals [13]. Since one of the diagonals is shorter than the other, the resonance frequencies will differ slightly for the two modes. If the corners are truncated exactly the right amount, the difference in frequencies will cause the 90° phase shift.

In this research the microstrip antenna was designed so that the polarization is nearly circular.

The resonance frequency f_r is a function of the effective length of the antenna, which can be determined using the following:

$$f_r = \frac{1}{2L_{eff}\sqrt{\mu_0\varepsilon_0}\sqrt{\varepsilon_{reff}}} = \frac{V_0}{2(L+\Delta L)\sqrt{\varepsilon_{reff}}} \tag{15}$$

where V_0 is the speed of light, ϵ_r is the dielectric constant, and f_r is the resonance frequency of the antenna. The extended incremental length ΔL due to the fringing effect can be found from

$$\Delta L = 0.412(h)\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{16}$$

where h is the height of the substrate.

A thicker substrate gives a higher bandwidth, as can be seen in $B = 3.77\frac{\epsilon_r-1}{\epsilon_r^2}\frac{t}{\lambda}$ and better efficiency [13], but at the same time if the material is too thick surface waves might be excited. For a patch operating at a frequency, f, the thickness, h, of the substrate should satisfy [15].

$$h \leq \frac{0.3c}{2\pi f\sqrt{\epsilon_r}} \tag{17}$$

where c is the speed of light in order to avoid surface waves.

The effective dielectric constant ϵ_{reff} is given by the following:

$$\epsilon_{reff} = \frac{(\epsilon_r+1)}{2} + \frac{(\epsilon_r-1)}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}_{for\ W/h>1} \quad (18)$$

Therefore the length of the antenna can be derived as

$$L = \frac{V_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (19)$$

Right triangles at the diagonal corners of the antenna are cut off, where the length c of the two sides of the triangle is equal, and c is calculated using [13].

$$c = \sqrt{\Delta S} \quad (20)$$

ΔS is the area of the triangle, which can be stated as

$$\frac{\Delta S}{S} = \frac{1}{2Q} \quad (21)$$

where, S is the area of the antenna patch, Q is the quality factor of the antenna patch

To determine the quality factor of the antenna Q, the effective loss tangent δ_{eff} as stated below is needed[16].

$$\delta_{eff} = \frac{1}{Q} \quad (22)$$

δ_{eff} can be determined using

$$\delta_{eff} = \delta + \frac{\Delta}{h} + \frac{P_r}{2\omega_0 w_e} \quad (23)$$

where Δ denotes skin depth and defined by

$$\Delta = 503\sqrt{\frac{\rho}{\mu_r f_r}} \quad (24)$$

where, ρ = conductor resistivity, f_r = resonance frequency, μ_r = medium permeability

The electrical energy w_e at resonance is

$$w_e = \frac{\varepsilon_0\varepsilon_r abV_0^2}{8h} \quad (25)$$

where, V_0 = antenna output voltage

Basically, the dielectric constant (ε_r) of the substrate and substrate height are very important factors that influence the variation of bandwidth as well as the surface waves. With increase in dielectric constant both the resonant frequency as well as the bandwidth decreases. So the antenna system becomes narrowband with increase in ε_r.

To meet with high bandwidth for delivering multimedia information, in this research, the relative dielectric constant of 2.2 (Duroid 5880) with loss tangent of 0.004 is chosen for the substrate material. The thickness of the substrate (h) is 2.9mm. The operating frequency of the antenna is at 2.45GHz.

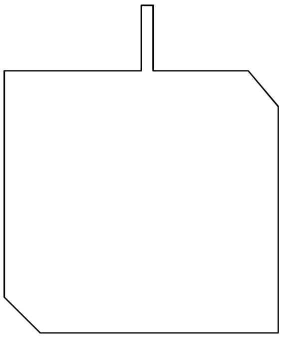


Figure 4: Final Element Design

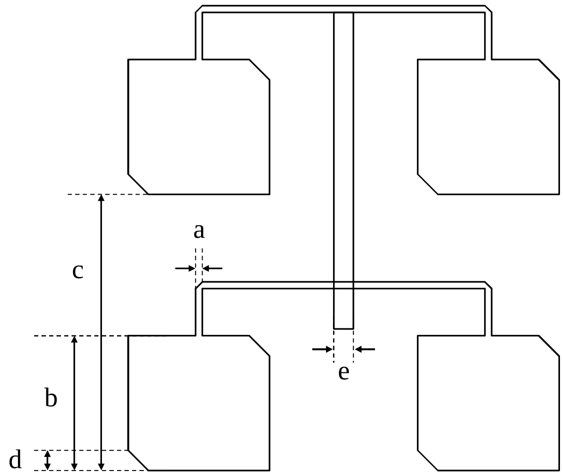


Figure 5: Geometry of a 2 × 2 Circularly Polarized Microstrip Antenna Array

Based on the simulation results by MATLAB programming, the proposed antennas resonate at 2.45GHz.

Table 1, summarizes the simulated results of dimensions of the proposed truncated cornor microstrip patch antenna as shown in Figure 4, and 2 × 2 microstrip antenna array as shown in Figure 5.

In order to increase the directivity of the antenna, an array of patches need to be constructed. To gain a small size of the antenna array, the 2 × 2 antenna array is chosen in this research as shown in Figure 5, which is a good tradeoff between the size of the antenna and the directivity.

Table 1: Dimension of the Proposed Antennas with 2.45GHz

Parameter	Value (mm)
a	0.52
b	41.5
c	75.5
d	3.3
e	3.5
h	3.1

The return loss of the proposed truncated cornor microstrip patch antenna is -42dB with 88MHz bandwidth as shown in Figure 6.

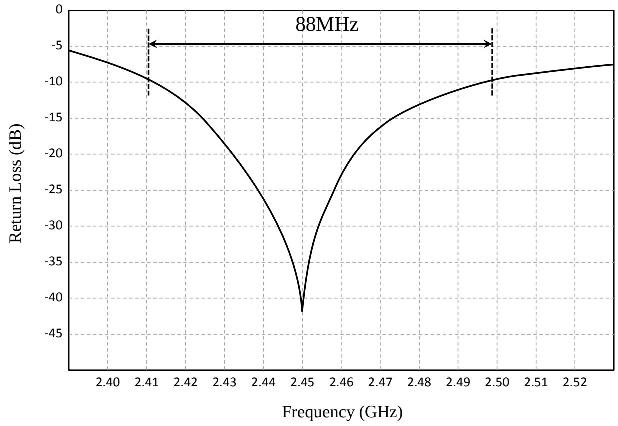
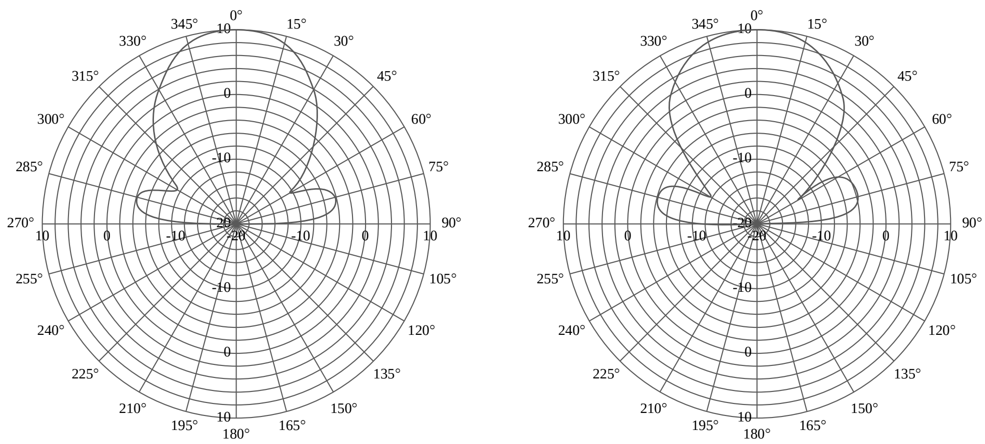


Figure 6: Return Loss of the Proposed Truncated Cornor Microstrip Patch Antenna

Simulated results of radiation pattern for right hand polarization of the proposed antenna array is shown in Figure 7.



(a) **(b)**

Figure 7: Radiation Pattern for Right Hand Polarization for the Proposed Antenna Array at 2.45GHz

(a) For Field Pattern with Scane Angle = 0°

(b) For Field pattern with Scane angle = 90°

Smart Antenna Design

Phase array antenna can be applied for beamsteering applications in smart antennas, especially, in airborn mobile communication.

In this paper, the phased array antenna is used to the proposed smart antenna.

It is possible to derive the array factor for a two dimensional rectangular array as [17].

$$\mathrm{AF}(\Theta, \Phi) = \sum_{n=1}^{N} \sum_{m=1}^{M} I_{mn} e^{j\alpha_{mn}} e^{j\xi_{mn}} \tag{26}$$

where

$$\xi_{mn} = \beta \hat{r} \cdot \hat{r}'_{mn} = \beta(x'_{mn} \sin\Theta \cos\Phi + y'_{mn} \sin\Theta \sin\Phi) \tag{27}$$

$$\alpha_{mn} = -\beta(x'_{mn} \sin\Theta_0 \cos\Phi_0 + y'_{mn} \sin\Theta_0 \sin\Phi_0) \qquad (28)$$

and Θ_0 and Φ_0 gives the direction of the main beam. I_{mn} and α_{mn} is the amplitude and phase of element mn. Thus by varying the the phase and amplitude of each individual element it is possible to synthesize the desired radiation pattern.

To achieve the proposed antenna array design as shown in Figure 7, the signal from each element is modified by a phase shifter and an attenuator, added together and sampled into the DSP. By looking at the quality of the signal in to the DSP and changing the out signals to the phase shifters and attenuators, it is possible to solve this as a control system problem.

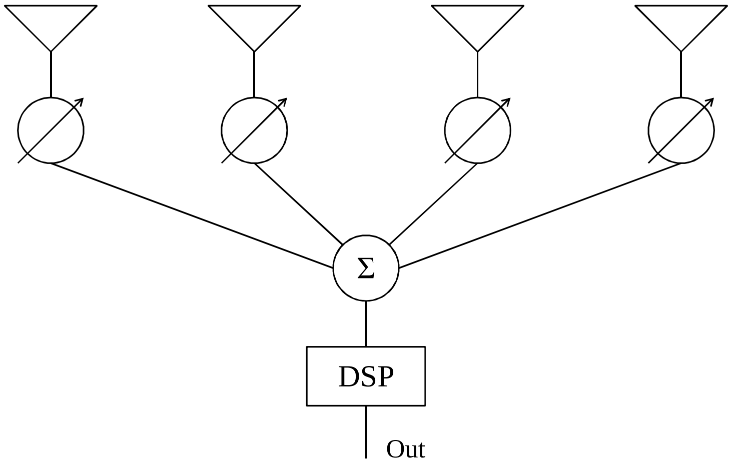


Figure 8: A Phased Array for Smart Antenna

Future Work

A dual feed circularly polarized microstrip patch antenna will be designed for the same application to compare to the proposed antenna system in this paper. The performance of both proposed antennas systems will be compared and analyzed.

CONCLUSIONS

In an attempt to pave the way for commercial and civil use of small drones around the world, a number of researchers in the antenna design are searching for a cheaper, smaller, simpler and more integrated way to implement smart antenna for small drone applications. This paper has been proposed a circularly polarized microstrip antenna array as a major component in the smart antenna system in the small drone communications system. Due to the operating frequency in GHz range, the FDSC model is adopted in this research to reduce the error on the frequency-dependent characteristics by including into the calculations. The proposed method can be fruitfully used in microwave CAD applications.

REFERENCES

1. *J. Garamone, "From the US Civil War to Afghanistan: A Short History of UAVs," Defend America [online journal], URL: http://www. defendamerica. Mil/articles/apr2002/a041702a. html [cited 05 May 2005], 2002.*
2. *A. Brecher, V. Noronha, and M. Herold, "UAV2003-A Roadmap for Deploying Unmanned Aerial Vehicles (UAVs) in Transportation," in US DOT/RSPA: Volpe Center and NCRST Infrastructure, Specialist Workshop, Santa Barbara, December.(http://www. ncgia. ucsb. edu/ncrst/meetings/20031202SBAUAV2003/Findings/ UAV2003-Findings-Final. pdf).(Accessed May, 2008), 2003.*

3. *D. M. Pozar, "Input impedance and mutual coupling of rectangular microstrip antennas," Antennas and Propagation, IEEE Transactions on, vol. 30, pp. 1191-1196, 1982.*
4. *R. Garg, Microstrip antenna design handbook: Artech House, 2001.*
5. *C. A. Balanis, Antenna theory: analysis and design: John Wiley & Sons, 2012.*
6. *P. Misra, "Planar Rectangular Microstrip Antenna for Dualband Operation," IJCST, vol. 2, 2011.*
7. *S. Pandey, S. Baudha, and A. Gupta, "Design and Simulation Based Studies of a Dual Band Antenna for WLAN/WiMax Application," 2012.*
8. *S. Malisuwan, M. Charoenwattanaporn, U. Goenchanart, and V. Ungvichian, "Microstrip Antenna for Wireless LAN Applications By Applying Modified Smith-Chart Representation," International Journal of The Computer, The Internet and Management, vol. 11, pp. 34 - 44, 2003.*
9. *S. Malisuwan, P. Neelakanta, and V. Ungvichian, "A Cole-Cole diagram representation of microstrip structure," APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY JOURNAL, vol. 15, pp. 167-174, 2000.*
10. *F. Abboud, J. P. Damiano, and A. Papiernik, "Simple model for the input impedance of coax-fed rectangular microstrip patch antenna for CAD," Microwaves, Antennas and Propagation, IEE Proceedings H, vol. 135, pp. 323-326, 1988.*
11. *S. Malisuwan and M. Charoenwattanaporn, "Modified Smith-chart representation as applied to microstrip antenna design for wireless LAN applications," in Electromagnetic Compatibility, 2003. EMC '03. 2003 IEEE International Symposium on, 2003, pp. 150-153 Vol.1.*
12. *J. C. Freeman, Fundamentals of Microwave Transmission Lines: Wiley, 1996.*
13. *R. A. Sainati, CAD of microstrip antennas for wireless applications: Artech House, Inc., 1996.*
14. *J. R. James and P. S. Hall, Handbook of microstrip antennas vol. 28: IET, 1989.*
15. *H. Pues and A. Van de Capelle, "Accurate transmission-line model for the rectangular microstrip antenna," in IEE Proceedings H (Microwaves, Optics and Antennas), 1984, pp. 334-340.*
16. *M. E.-d. Ahmad, "Energy Harvesting Using a Cheap Easy-to-Fabricate FM Rectenna," in The 2009 World Congress on Electronics and Electrical Engineering WCEEENG, 2009, pp. 6-9.*
17. *W. L. Stutzman and G. A. Thiele, Antenna theory and design: John Wiley & Sons, 2012*